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ABSTRACT

The relationship to readability of ten variables characterizing structural properties of mathematical prose was investigated in elementary algebra textbooks. Readability was measured by algebra student's responses to two forms of cloze tests. Linear and currilinear correlations were calculated between each structural variable and the cloze test. The results indicated that explanatory material, sentence length, percentage of mathematical symbols and percentage of difficult words had significant linear correlaticns with readability. In illustrative material, percentage of mathematical symbols and percentage of mathematics vocabulary had significant linear correlations with readability. Departures from linearity were significant for sentence length and percentage of reader-directed sentences in explanatory material, and percentage of difficult words in illustrative material. [Not available in hardcopy due to marginal legibility of original document.] (Author/CT)

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Measuring the Readability of Elementary Algebra Using the Cloze Technique

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In the past, investigations of the readability of mathematical English have been extremely limited. Most studies have attempted to apply to mathematics readability formulas that were developed for use with ordinary English. Kane (1970) has outlined the difficulties inherent in this approach. Vocabulary differences between mathematical English (ME) and ordinary English (OE) make inapplicable formulas that use a count of words not on a list of familiar words. Words that are familiar in OE may have special meanings in ME and, hence, may not be familiar. Also words that are familiar in ME may not appear on the list. A more fundamental reason that the formulas are not applicable is that they apply only to prose portions of the text. The readability of symbolic material is completely neglected in these formulas.

The purpose of this study was to investigate structural variables that might predict the readability of ME as found in first-year algebra textbooks. A large portion of school mathematics textbook material can be classified either as explanatory, in which a concept is defined and explained, or as illustrative, in which specific problems or exercises that illustrate a concept

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are worked out for the reader. These two types of ME were investigated separately to determine if their difficulty was predicted differently by the structural variables. The structural variables were also investigated to see if their relationship with readability was linear. If the relationship is linear for a particular variable, then its predictive value is applicable over a range of readability levels.

The criterion of difficulty is of critical importance in any readability study. The most common criterion is the score on a test, usually multiple-choice, over the content of the passage being analyzed. The most obvious drawback of this criterion is that difficult questions can be constructed for easy passages and vice versa. Many readability formulas use this criterion because nationally normed tests, such as the McCall-Crabbs, are available for OE passages. The lack of such passages and tests for ME is one reason that readability formulas for ME have not been developed.

Reading difficulty can also be obtained by having judges rate the passages. This method was used for OE by Elley (1969) with promising results. He found that judges' ratings correlated highly with structural variables and with readability formula scores. Judges' ratings are much simpler to obtain than other measures that have been used as criteria. Rankings for a large number of passages, however, are difficult to obtain. Elley obtained rankings of only 16 passages and he was unable to build an interval scale of difficulty by paired comparisons.

In a study of mathematical word problems, Kilpatrick (1960) used the subjects' ability to write the appropriate equation for a problem as the readability criterion. This method avoids the disadvantages of comprehension tests, but it is difficult to interpret when a partially correct equation is produced. The method is, of course, not applicable to other types of ME passages.

A readability criterion that has gained wide acceptance is the cloze procedure, developed by Taylor (1953). A cloze test is constructed by deleting words from a passage and inserting blanks. The reader is instructed to replace the words, using clues from the remaining context. The number of words replaced incorrectly, averaged across readers, is taken as a measure of the passage's difficulty.

The cloze procedure is attractive because of its objectivity, and it correlates highly with other measures of readability (Bormuth, 1966; Hafner, 1963; Rankin, 1964). However, cloze tests are laborious to construct. Furthermore, although no one has investigated the question, mutilating a passage by inserting blanks may, particularly in ME, increase reading difficulty because of the unusual appearance of the text.

Despite these limitations, the cloze test can be applied to ME, including symbolic and graphical material, if special agreements are made. Each graphic sign in a passage must be classified as a single item for deletion. In the following discussion, the

term "token" refers to an occurrence of a sign (word, algebraic symbol) in context and the term "type" refers to the listing of a sign as in a dictionary. The number of tokens in a passage is simply the number of signs that occur; the number of types is the number of different signs that occur.

Signs in OE are easily classified into word tokens: a token is separated by spaces from other tokens. In general, a word token is eligible for deletion if there is a space before and after it. Although there is no simple definition of a math token, Hater (1969) showed how to identify individual tokens in an ME passage. Math tokens usually do not have a phoneme-grapheme relation to spoken words, nor do they always have a one-to-one correspondence with words. Generally, a math token is the smallest unit that independently conveys the intended meaning of the part of the passage in which it occurs. In an ME passage, a math token is any sign that is not a word token, punctuation, or drawing. Each word token and math token is eligible for deletion, including tokens that appear in tables, charts, on graphs, and as labels for drawings.

The validity of the cloze test as a readability criterion for ME was investigated by Hater (1969), who used five forms of the cloze test for each of five passages. Average cloze score was highly correlated ($r = .83$) with reading difficulty as measured by multiple-choice tests. Single forms of the cloze test were not highly correlated with reading difficulty. However, all but

one form ranked the passages in the same order of difficulty. Hater recommended use of the cloze procedure as a measure of the readability of ME.

Definitions of Structural Variables

The unique nature of mathematical English as a combination of a natural language (English) and other languages, such as sentential calculus, algebraic notation, and the like (Kane 1970), makes it necessary to consider additional structural variables beyond those commonly used in readability formulas for ordinary English.

Average sentence length

Since ME is written in English, it is reasonable to expect that some structural variables of English are important determiners of difficulty. In many readability formulas, a measure of sentence length accounts for a large portion of the reading difficulty of a passage. The definition of sentence length in this study was the average number of words per sentence in the passage. The measure was obtained by counting the number of word and math tokens and dividing the total by the number of sentences in the passage.

Percentage of personal words

A personal interest or concreteness measure has been used in some formulas. Flesch (1950), for example, used the percentage of "definite words" which had a higher correlation with comprehension than did sentence length. The percentage of personal words -- like Flesch's variable -- was intended to provide a measure

of the abstractness of ME. Personal words include names of people; common nouns with a natural gender, such as "father"; personal pronouns; and possessive pronouns. The measure was obtained by counting the personal word tokens and dividing the total by the number of word tokens.

Percentage of difficult words

There are two general procedures for determining word difficulty. One is to determine the average length in letters or syllables of the words of a passage. The other is to determine the percentage of words in the passage that are not on a previously prepared list of familiar words. The latter procedure was used in this study since word length seemed less able to differentiate between ordinary English words and mathematics vocabulary words. The original Thorndike 1000 word list was used (Thorndike & Lorge, 1944). The measure was obtained by counting each word token that was not on the list and dividing the total by the number of word tokens in the passage.

Percentage of mathematics vocabulary words

As pointed out earlier, a major drawback in applying existing readability formulas to ME is that they do not account for its specialized vocabulary. A list of familiar mathematical vocabulary words does not exist although work is in progress to develop one. Without such a list, the alternative is to count all of the mathematical vocabulary words in the passage. In a study of mathematical vocabulary, Byrne (1970) gathered words from mathematics texts for grades 4 through 12 and compiled a list of 1165

words and phrases. The percentage of mathematical vocabulary words in this study was obtained by counting each word token that appeared on the Byrne list and dividing the total by the number of word tokens.

Percentage of mathematics symbols

Heavy use of symbolism is an obvious characteristic of ME. Symbolism in the form of well-known formulas and in the detailed solution of equations is highly redundant and should aid reading. On the other hand, symbolism is extremely concise and may decrease readability because of its technical and abstract nature. In either case, this variable seemed a reasonable one to study. The measure was obtained by dividing the number of math tokens by the total number of tokens in the passage.

Number of implicit numbers, operations, and relations

In a passage about a mathematical concept, it may be important whether the processes involved are stated in words or in symbols. For example, the statement "The sum of 6 and 2 is 8" can be expressed symbolically as "6 + 2 = 8", where the "+" and the "=" are implicit symbols and must be inferred from the statement. In a reading study, Davis (1967) found that the ability to draw inferences from content accounted for a large portion of the variance of reading skills, ranking second only to recall of word meanings. The variable used in this study to reflect this characteristic of ME is the number of implicit numbers, operations, and relations. In Kilpatrick's study (1960), the variable contributed significantly to the prediction of the readability of word problems.

The measure is obtained by noting occurrences of processes that are stated in words or implicitly given in the context. The appropriate translation to symbolic form is made, and each occurrence of a number, operation, or relation that does not appear explicitly in the passage is counted.

The last four variables were selected because of their ability to reflect the reading difficulty of abstract prose material.

Percentage of questions

In studies of written material, Frase (1967) and Rothkopf and Bisbicos (1967) found that the number and position of questions in a passage affects learning. Davis (1967) identified the ability to find answers to explicit questions as an important reading skill. The percentage of questions was obtained by counting the number of questions in the passage and dividing by the number of sentences.

Percentage of reader-directed sentences

Abstract written material may be less difficult to read if the author attempts a direct contact or communication with the reader. Abstract prose frequently contains many passive verbs and other grammatical forms that can cause difficulty in interpretation. Some investigators of readability have attempted to identify grammatical classes that reflect stylistic complexity. If written material is directed to the reader, the style will be "simple" in the sense that relative clauses, passive sentences, and other less "direct" sentence constructions are not used.

The measure used in this study was obtained by counting the number of sentences containing a form of the pronoun "you," the number of imperative sentences, and the number of non-rhetorical questions, and dividing by the total number of sentences in the passage.

Number of graphic clues

In ME passages, it is fairly common to find graphs, tables, and other pictorial material that are not classified as word or math tokens. It is clear that these are intended as reading aids and should, therefore, be included as structural features of ME that may affect readability. The measure of the variable, number of graphic clues, was obtained by counting each occurrence of a graph, number line, table, diagram, or other symbolic material that is not a word token, math token, or punctuation.

Percentage of connected sentences

A passage in which the ideas follow closely may be highly readable. On the other hand, if one sentence is difficult, the following ones may also be difficult. Percentage of connected sentences is a variable designed to measure the extent to which a sentence depends on the one preceding. The measure was obtained by counting the number of sentences that begin with "linkers" such as "and," "but," "since" and so on, in addition to sentences that began with adverbial phrases or clauses. The number of these sentences was divided by the total number of sentences in the passage.

Methods and Procedures

The passages for the study were selected from nine elementary algebra textbooks. Explanatory (E) passages were chosen that presented a single concept. The 50 E passages represented a wide range of topics and difficulty. For the analysis of structural variables, the first 250 tokens were used. On the tests constructed from the passages, the entire sentence containing the 250th token was included. The 50 illustrative example (X) passages were selected from the same nine textbooks. The X passages presented the solution of equations, word problems, factorizations, and other algebraic problems. The examples were chosen to represent a variety of types of exercises. Since solutions are limited in length, each X passage contained 175 tokens.

For each passage, two forms of the cloze test were constructed: Form A by deleting the first and every fifth following token, and Form B by deleting the third and every fifth following token. Each test over the E passages contained 50 items, and each test over the X passages contained 35 items. Hater's results (1969) suggested that two forms would be adequate.

The tests were given to 860 first-year algebra students in four high schools in New York State. The students were of average ability. Some were tenth and eleventh graders, but most were in the ninth grade. One of the textbooks used to select passages was being used in three of the schools; the other eight textbooks were not being used.

Each student received a packet containing directions, an E test and an X test. In half of the packets, the E test was first, and all possible combinations of test form pairings were evenly distributed. Each form of each test was given to students in at least two of the schools, and most were given to students in all four schools. The test period was 30 minutes. The regular classroom teacher administered the tests using directions provided by the investigator. All testing was carried out during the week of November 16 to 20, 1970.

Data and Analysis

For four of the ten structural variables (percent of reader-directed sentences, number of graphic clues, percent connected sentences, and number of implicit symbols), values were determined by a second person as well as by the investigator, and the average of the values was used. The mean values of each of the structural variables for the E and X passages are given in Table I.

The values in Table I indicate some of the structural differences between E and X passages. The striking significant difference in MT was expected since many of the X passages were almost completely symbolic. The shorter average SL of X passages was also expected since many of the sentences of the X passages consisted of equations, and at this grade level the equations are quite short and simple. The difference in CS evidently reflected the contrast between E passages, which were continuous discourse, and X passages, which were composed of linguistically disconnected

Table I

Means and standard deviations of structural variables and difficulty, and t-values for test of differences between E and X passage means.

Variable	E Passages Mean	E Passages S.D.	X Passages Mean	X Passages S.D.	t
Average sentence length (SL)	21.12	5.40	17.11	6.24	3.44**
Percent math tokens (MT)	27.60	10.95	52.21	17.57	8.41**
Percent personal words (PW)	3.75	2.20	3.02	2.62	1.51
Percent difficult words (DW)	22.83	6.28	23.71	8.20	0.60
Percent questions (Q)	6.11	8.43	7.31	9.95	0.65
Percent math vocabulary (MV)	23.10	6.80	22.28	7.80	0.56
Percent reader-directed sentences (DS)	16.40	18.70	26.91	21.52	2.61*
Number of graphic clues (GC)	0.92	1.58	0.80	1.26	0.42
Percent connected sentences (CS)	33.16	15.72	21.53	18.04	3.44**
Number of implicit symbols (IS)	5.72	6.54	5.06	4.91	0.58
Reading difficulty (cloze)	18.00	4.25	17.01	3.75	1.24

*p<.05 **p<.01

12

steps in the solution of equations. The remaining significant difference was in DS. This difference probably reflects the combination of imperatives and direct questions in X passages.

The readability criterion used in the study was obtained by averaging the means of the Form A and Form B cloze test scores for each passage. The reliability of the combined score was computed by an analysis of variance. For the E passages, the single form of reliability was 0.57, and the combined forms reliability was 0.73. For the X passages, the single form reliability was 0.63, and the combined forms reliability was 0.77. The combined form reliabilities are high enough for comparisons of overall combinations of passages, but not for comparisons of single passages. The single form reliabilities are close to the correlation found by Hater (1969) between a single form of a cloze test and comprehension test scores (0.54). Evidently, combination of two forms is almost as reliable as the combination of five forms.

The F-ratios in Tables II and III indicate that for E and X passages the two forms were not significantly different in difficulty and that the passages were significantly different in difficulty.

Product moment correlation coefficients and correlation ratios were used to investigate the relationship between readability and each of the structural variables. Eta values were computed for the regression of the structural variables on readability, using six intervals of reading difficulty.

Table II

Test by Form ANOVA for E Passages

Source	Sum of squares	df	Mean square	F
Between tests	1846.7	49	37.69	3.69*
Between forms	21.4	1	21.40	2.09
Error	501.1	49	10.22	
Total	2369.2	99		

*p < .01

Table III

Test by Form ANOVA for X Passages

Source	Sum of squares	df	Mean square	F
Between tests	1417.65	49	28.93	4.37*
Between forms	0.34	1	0.34	0.05
Error	327.61	49	6.62	
Total	1745.26	99		

*p < .01

Correlation coefficients calculated using array means are usually higher than those using individual scores. This must be remembered in interpreting the values of r in Tables IV and V. For each variable, F-ratios, F_1, F_2, and F_3, were computed to test the significance of the correlation ratio, eta; the linear correlation coefficient, r; and the departure from linearity, respectively.

The relationships between the structural variables and readability were different for the E and X passages. One variable, percent of math tokens had a significant linear correlation with readability in both types of passages. This variable alone would provide a fair prediction of the readability of these two types of elementary algebra passages. Average sentence length was significantly correlated with the readability of E passages, but there was also a significant departure from linearity. Apparently, the shorter sentence length of X passages reduced the importance of the variable for this type of material. The percentage of difficult words (DW) had a significant negative linear correlation with the reading difficulty of E passages. Although DW did not have significant linear correlation with readability in X passages, the correlation ratio and the departure from linearity were significant. The nature of this relationship will be discussed later. Another contrast of the E and X passages was provided by the math vocabulary measure. In the X passages, the linear correlation of MV and readability

Table IV

Product moment and eta correlations of E passage difficulty with each structural variable, and the F ratios obtained from tests of significance of correlation ratio, linear correlation, and departure from linearity. (N = 50).

Variable	r	eta	F_1	F_2	F_3
Average sentence length (SL)	-.320	.622	5.56***	5.45*	5.12**
Percent math tokens (MT)	-.498	.596	4.84**	15.82***	1.83
Percent personal words (PW)	.100	.137	<1	<1	<1
Percent difficult words (DW)	-.368	.429	1.98	7.45**	<1
Percent questions (Q)	.124	.227	<1	<1	<1
Percent math vocabulary (MV)	-.254	.367	1.37	3.37	<1
Percent reader-directed sentences (DS)	.110	.543	3.68**	<1	4.41**
Number of graphic clues (GC)	-.062	.400	1.68	<1	2.04
Percent connected sentences (CS)	-.196	.236	<1	1.93	<1
Percent implicit symbols (IS)	-.029	.401	<1	<1	1.76

*p< .05 **p< .01 ***p< .001

Table V

Product moment and eta correlations of X passage difficulty with each structural variable, and the F ratios obtained from tests of significance of correlation ratio, linear correlation, and departure from linearity. (N = 50)

Variable	r	eta	F_1	F_2	F_3
Average sentence length (SL)	-.145	.381	1.50	1.02	1.60
Percent math tokens (MT)	-.424	.482	2.66*	10.52**	<1
Percent personal words (PW)	.188	.450	2.23	1.75	2.30
Percent difficult words (DW)	-.210	.623	5.57***	2.22	6.18***
Percent questions (Q)	.275	.391	1.59	3.93	1.00
Percent math vocabulary (MV)	-.438	.492	2.81*	11.37**	<1
Percent reader-directed sentences (DS)	-.080	.354	1.26	<1	1.51
Number of graphic clues (GC)	-.020	.213	<1	<1	<1
Percent connected sentences (CS)	.041	.397	1.65	<1	2.04
Percent implicit symbols (IS)	-.167	.232	<1	1.38	2.37

*p<.05 **p<.01 ***p<.001

was highly significant, but in the E passages the correlation only approached the .05 level of significance. The passages did not differ significantly in percentage of math vocabulary, so the differences in the correlations must have been due to the nature of the passages. The investigator expected that math vocabulary would be an important predictor; but he would have predicted the correlations with readability for the two types of passages to be the opposite of what they are. The continuous discourse in the E passages may permit the meaning of relatively more words to be inferred from the context, thereby reducing the impact of vocabulary. In contrast, many of the math vocabulary words in the X passages are independent of other verbal material and consist of phrases, such as "commutative property of multiplication," used to justify particular algebraic operations used in the solution of a problem. Another explanation may be that in E passages, the names of numbers, such as "two," and operations, such as "sum," are written as word tokens and are thus counted as math vocabulary items. In X passages, these words are usually written in symbolic form, as "2" and "+." The result is that although the percentage of math vocabulary words may be the same, the E passages may contain many easy math vocabulary words. Math vocabulary items in the X passages are likely to be more difficult. Once data are available on the familiarity of words and phrases in the Byrne list, the math vocabulary variable may be adapted to yield a more sensitive measure.

None of the variables representing facilitation of reading were significantly correlated with readability. The percentage of questions approached the .05 level in the X passages. A more refined measure that reflected the type and position of questions might yield a significant positive correlation. In the E passages, the percentage of reader-directed sentences was positively correlated with readability. Although r was not significant, the correlation ratio was, indicating that the relationship may be curvilinear. Percentage of personal words had a small positive linear correlation with readability. In the X passages, the correlation approached the .05 level.

Additional information on the relationships between structural variables and readability is provided by plots of the means of the arrays of those variables exhibiting a significant departure from linearity. The number of arrays is too small to characterize the curves precisely, but some inferences can be made about the relationships. The plots are given in Figures 1 to 4.

Figure 1 suggests that in E passages readability is relatively unaffected by sentence length until very long sentences are encountered. Attempts to decrease reading difficulty in ME passages by decreasing the sentence length may therefore have little effect once extremely long sentences have been eliminated.

The nature of the relationship in Figure 2 between RD and the difficulty of E passages is apparently due to two passages that have high RD and high difficulty. In a larger sample, the relationship may be linear.

In Figure 3 there appears to be an unmistakable curvilinear relationship between DW and the difficulty of X passages. However,

Figures 1 - 4. Plots of the means of structural variables which have non-linear relationships with readabilty.

E Passages

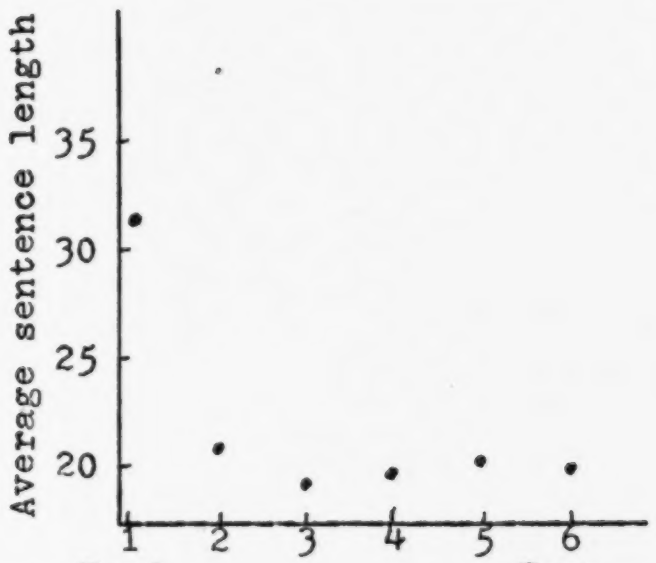

Figure 1

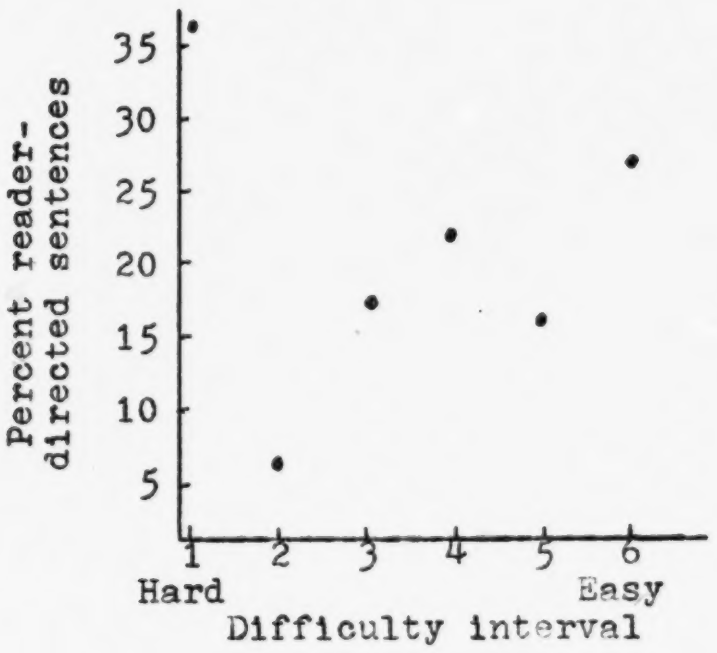

Figure 2

X Passages

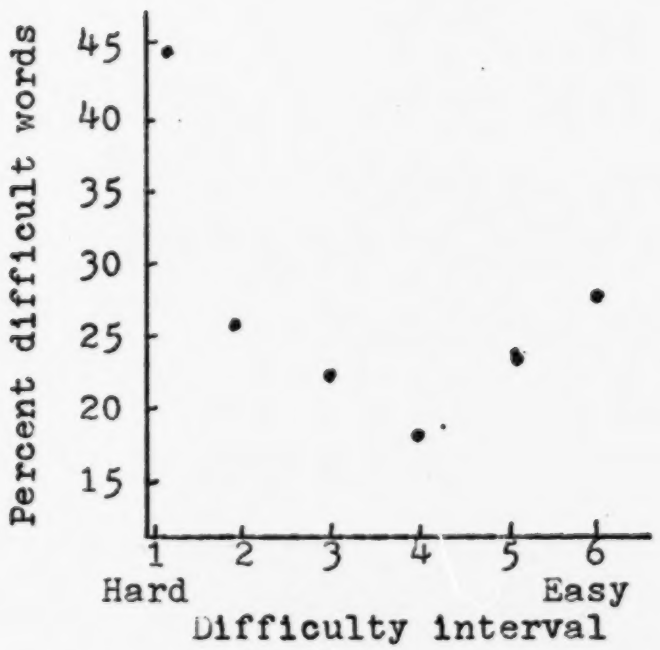

Figure 3

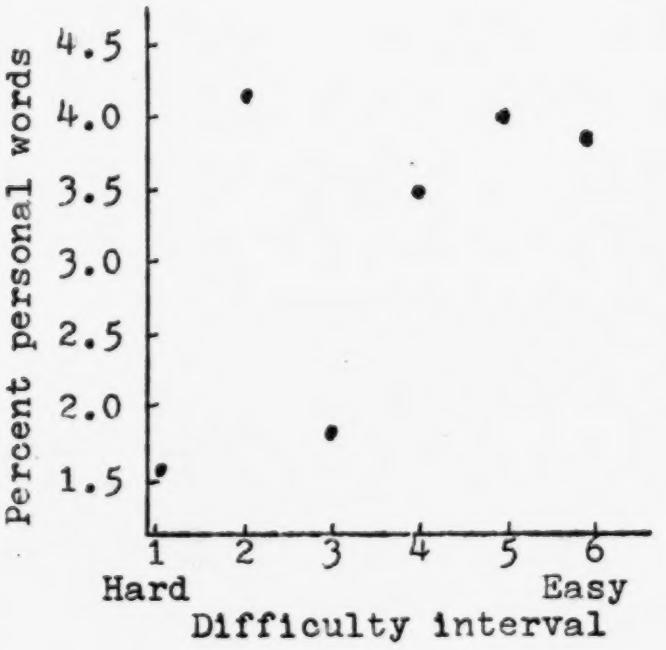

Figure 4

the number of passages in the very difficult and very easy intervals is small. Also, the relationship is linear for E passages. The curvilinear relation in Figure 3, therefore, should be interpreted cautiously. If the curvilinear relationship between DW and difficulty is a true characteristic of X passages, the predictive value of the variable is questionable since the same value can correspond to an easy or a difficult passage.

The relationship between personal words and difficulty of X passages approaches significant curvilinearity. Since the average value of PW is only about 3% in ME passages, slight variations may account for the nonlinear nature of the graph in Figure 4. It is possible that higher values of PW could produce a more definite relationship, but personal words are not used extensively in ME passages.

Summary and Conclusions

The relationship to readability of ten variables characterizing structural properties of mathematical prose was investigated for 50 explanatory (E) passages and 50 illustrative example (X) passages from elementary algebra tests. The E passages had greater average sentence length and more connected sentences. The X passages had a greater percentage of math tokens and reader-directed sentences.

Readability was measured by algebra students' responses to two forms of cloze tests over each passage. The combined forms had

reliability coefficients of 0.73 and 0.77 for the E and X passages respectively. Linear and curvilinear correlations were calculated between each structural variable and the cloze test. In E passages, sentence length, percentage of math tokens, and percentage of difficult words had significant linear correlations with readability. In X passages, percentage of math tokens and percentage of math vocabulary had significant linear correlations with readability. Departures from linearity were significant for sentence length and percentage of reader-directed sentences in E passages, and percentage of difficult words in X passages.

The results of the study confirm the view that ME is structurally different from OE. The sentence length and difficult word variables commonly used in OE readability formulas were not similarly related to the readability of ME passages. Both variables showed evidence of curvilinear relationships with the readability of ME but these relationships may be due to the small number of passages in the extreme intervals of difficulty.

The structural variables investigated in this study show promise of providing a significant combined prediction of the readability of elementary algebra ME passages. A multiple regression analysis will be performed using the ten structural variables as predictors and the cloze test as the readability criterion. The results of such an analysis, done separately for the explanatory and illustrative passages will provide specific information about how these two types of algebra passages differ from each other

and from ordinary English.

At the present time, intuition, experience, and knowledge of readability factors of ordinary English provide the only approach to determining the readability of mathematical English. It is apparent that the two types of elementary algebra passages investigated in this study have distinct and somewhat different structural characteristics that are related to readability. Further analysis will provide specific information about the relative weights of the structural variables in relation to readability. In the future, more refined measures of variables such as mathematics vocabulary may yield insight into the nature of mathematical English. When precise determinations of these variables are made, mathematical English can be written with an awareness of specific existing reading difficulties. With this knowledge, attempts to make mathematical English readable promise to be more effective.

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